Explorations of Year 10 students' conceptual change during instruction

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Abstract

This article reports on a classroom-based case study of a group of six Year 10 students, within a class of 23 students. The study implemented constructivist-informed teaching and learning approaches within a classroom setting in the topic of optics and documented any changes in the conceptual understanding students had about seven central concepts of geometrical optics over a teaching sequence lasting nine weeks.

Introduction

As a practising science and physics secondary school teacher with seventeen years experience in the classroom I consistently found evidence of students' alternative conceptions in many areas of science and particularly in physics. I found that in spite of my best efforts the traditional teaching strategies employed were not always successful in changing these alternative conceptions. This was the prime motivation for undertaking a research study which essentially was a search not only for a deeper insight into students' understandings of the world, but also an exploration of different teaching strategies to improve the conceptual understanding of the students.

The literature into students' understandings of science is substantial (as illustrated by the extensive bibliography by Duit, 2002) and supports my classroom observations. A significant finding of many research studies has been that students' ideas of the world are often formed before any formal instruction and are often quite different from scientifically accepted ideas. In addition, many studies have found that alternative conceptions are particularly resistant to change, or they change in unexpected ways, within the formal setting of the classroom.

This paper outlines a research study that initially explored the pre-instructional understandings of geometrical optics of a group of Year 10 students. The exploration of students' understandings continued throughout a teaching sequence that employed strategies that specifically targeted the students' alternative conceptions. I undertook the dual roles of teacher and researcher.

The theoretical framework that underpins this study is provided by the theory of constructivism. Constructivism, as a theory of learning, recognises that learners construct, rather than absorb, new ideas within the context of their personal knowledge, and they actively generate meaning from experience. Learning is viewed as conceptual change produced by the construction and acceptance of new ideas or the restructuring of existing ideas of the learner.

Constructivism has provided the theoretical base for the exploration of teaching and learning approaches that establishes the need to directly address the extant knowledge of the individual if any conceptual change is to take place (Posner, Strike, Hewson & Gertzog, 1982). This has led to teaching and learning strategies that allow students to engage in the construction of knowledge from the perspective of their own conceptual frameworks. In contrast, teaching and learning strategies based on traditional approaches of direct instruction have not recognised the need to take the students' present ideas into account when trying to change them.

Constructivist-informed teaching approaches to the process of learning are viewed as activities that explicitly aim to help students to make the constructions that lead to a conceptual understanding of the scientific points of view (Treagust, Duit & Fraser, 1996). Within such approaches students are active learners who come to the classroom with prior notions of natural phenomena that they use to make sense of their everyday experiences (Laverty & McGarvey, 1991). As students actively make sense of the world by constructing and reconstructing their own viable meanings (von Glaserfeld, 1989), constructivist-informed teaching approaches then become a matter of creating situations in which students actively participate in activities that enable them to make their own viable explanations of their sensory experiences (Wood, 1995). A number of research studies (Fetherstonhaugh & Treagust, 1992; Lederman, Gess-Newsome & Zeidler, 1993; Confrey, 1990) have noted a lack of research into the implementation of constructivist-informed teaching and learning approaches within the classroom while Duit (1995) has suggested that "more research is necessary to investigate whether constructivist teaching sequences really result in constructivist learning processes" (p. 280).

The constructivist-informed teaching and learning strategies used in the teaching sequence followed a model of conceptual change developed by Driver and Oldham (1986). This involves an initial orientation stage to give students opportunities to develop a sense of purpose and motivation for learning the topic. After orientation, there is a stage where different ideas are elicited through bringing to conscious awareness the students' own ideas. Through the clarification and exchange of different ideas a stage may be reached where some students need to reconstruct new ideas. This reconstruction of ideas may require student exposure to conflict situations that, in turn, may require a time for evaluation and then the opportunity to apply new ideas to a variety of situations. Finally, any restructuring of ideas requires students to reflect on how their ideas have changed.

The call for more research into constructivist-informed teaching and learning approaches is particularly relevant in the area of secondary school optics. A significant number of studies have explored the way individuals understand optical phenomena at different ages and backgrounds (Galili, 1996). A major finding of the accumulated data from these studies is the occurrence of alternative conceptions of optical phenomena that have been resilient to change through formal instruction in the classroom. Research into students' understandings of optics has also pointed to constructivist-informed approaches as a means to address the central concepts of optics, which this study sought to do.

Description of study

This section has three parts which describe the (i) key concepts, (ii) teaching sequence, and (iii) data collection instruments.

Key concepts

The study implemented constructivist-informed teaching and learning approaches within a classroom setting in the topic of optics and documented any changes in the conceptual understanding students had about seven central concepts of geometrical optics (Table I) over a teaching sequence. The investigation was a classroom-based case study of a group of six students, within a class of 23 students. The teaching sequence consisted of three 47 minute lessons per week over a 9 week period.

Table I: Listing of Key Concepts of Optics

Number		Descriptions of key concept
1.		Light must enter the eye in a direction from the object before vision of that object is possible.
2.		Light travels in straight lines until it hits something.
3.		Each point on a luminous object emits light in all directions.
4.	(a)	When light is reflected from mirrored surfaces the rule of reflection holds true.
	(b)	Light reflects in all directions from a non-mirrored surface.
5.	(a)	In general, light will change direction when passing from one transparent material into another.
	(b)	Light will not change direction when passing from one transparent material into another if it hits the second material at right angles to its surface.

6.		The colour of an object is the colour of the light that is reflected by the object.
7.	(a)	All the light from each point on an object that passes through a lens, or reflects off a mirror, contributes to the formation of a corresponding image point.
	(b)	The divergent light from each point on the object that passes through a lens, or is reflected from a mirror, either converges to the corresponding point on the real image or appears to diverge from the corresponding point on the virtual image.

Teaching sequence

At the beginning of the teaching sequence students were introduced to optics through the administration of a question sheet designed to elicit the concepts the students had about: (a) the direction of light from luminous sources to be able to see a non luminous object, (b) if vision is possible in the absence of light, and (c) if one could 'feel' a stare. The subsequent clarification and exchange of ideas through a class discussion led to further discussions following activities described as:

1. Student generated experiments to test if one could attract someone's attention through just staring at them. The experiments disconfirmed the alternative conception that through the act of staring something is emitted from the eye that will be detected by the person being stared at.
2. Students with alternative conceptions about vision in the absence of light were exposed to a disconfirming demonstration where they could experience the total absence of light in a photographic darkroom.
3. A 'senses' analogy was introduced to assist in the restructuring of concepts held about vision. In the analogy, something (for example, a sound, smell, or possibly light) activates a sense receptor, which then sends a message to the brain that interprets the message as a particular sense stimulus. This analogy was used to give plausibility to the key concept that light must enter the eye for vision to occur.

The students were given the opportunity to use their reconstructed concept of vision in a variety of situations throughout the teaching sequence. The application of the concept of 'the eye as a light detector' gave plausibility to other concepts addressed. For example, the concept of detection of light from an object is only possible through a straight section of pipe gave plausibility to the concept of rectilinear propagation of light. Also, the concept of the eye as a light detector was used to assist in the understanding of image formation in mirrors and lenses. The students were invited on many occasions throughout the teaching sequence to reflect on their original concepts of vision and how their concepts changed.

Teaching strategies were employed on a number of occasions where the explicit attempt was made by the teacher to promote conceptual conflict through the use of disconfirming, or 'surprise' demonstrations (Driver & Oldham, 1986), or a 'predict-observe-explain' (POE) technique (White & Gunstone, 1992). Some examples of the POE activities used were:

1. Several POE activities in relation to the students' understanding of shadows and pinhole images were modified from those developed in the Feher and Rice (1988) and Rice and Feher (1987) studies. Predictions were to be made as to the shape of images, or shadows, after changes were made to an aperture or obstacle shape that was placed between a light source and a screen in a darkened classroom.
2. A POE activity was developed from a disconfirming demonstration described by Singer (1979) to locate the position of the virtual image in plane mirrors. The disconfirming demonstration consisted of two candles on either side of a plane glass sheet with one of the candles lit. Through a parallax test, and direct observation, the alternative conceptions about the position of the virtual image were tested. As part of the POE technique the students were to predict the nature and the position of the virtual image with changes in the position of the observer as well as changes in the position of the lit candle. Another POE activity in relation to images in plane mirrors was used where students were to predict any changes to the image if the object, in this case a person, moved further away from a mirror.
3. A POE activity was developed from a probe of understanding used by Goldberg and McDermott (1987) about real images in converging lenses. From an initial arrangement of a luminous source, converging lens and a screen showing the real image, students were to make predictions about what would happen to the image if certain changes to the arrangement were made. For example, removing the lens completely or covering half of it or removing the screen.

Some further examples of disconfirming demonstrations that were employed include:

1. A red filter was placed in the path of blue light to disconfirm the alternative

conception that the function of a filter is to dye, or change the colour, of the incident light after it passes through the filter.

2. A translucent screen was placed in a converging lens system (light source and lens) at the position of the real image but only covering half of the image. This demonstration, developed from one described by Conery (1983), disconfirmed the alternative conception that an aerial image is non-existent.

All the key concepts of the study (Table I) were addressed in the teaching sequence. However, time constraints imposed difficulties in providing the students sufficient time to fully explore their developing ideas about colour (key concept 6) and image formation in converging lenses (key concepts 3 and 7) in terms of applying new ideas to a variety of situations and reflection of how ideas were changed.

Data collection instruments

Multiple methods of collecting data, involving a range of qualitative and quantitative approaches, enabled triangulation to be used to support the internal validity of the study. The qualitative methods adopted included the researcher/teacher journal, which incorporated classroom observations, student workbooks, and three semi-structured interviews with each participating student of the study. The quantitative methods that were adopted included a questionnaire survey to determine the students' perceptions of the classroom environment that adopted a constructivist-informed approach to teaching and learning as well as classroom documentation that included tests, assignments, concept maps, worksheets and surveys. It should be noted that the focus of this article is on the conceptual change students have about concepts related to optics and so the data associated with the questionnaire survey to determine the students' perceptions of the classroom environment is not provided. A full discussion of the data associated with this aspect of the study can be found in Hubber (2005).

The first two semi-structured interviews were designed to elicit the pre-instructional concepts held by the students in terms of the key concepts of the study. The first interview probed the conceptual understanding of the first three key concepts (see Table I) while the second interview probed the conceptual understanding of the last four key concepts (see Table I). The probes of understanding in the interviews generally took the form where some common stimulus, pictured in a diagram or presented physically, was initially presented to the student and then the student's interpretation of, or explanation for the stimulus, was sought without judgement as to the validity of the explanation (White & Gunstone, 1992).

In the first interview an example of the questions asked came from a Stead and Osborne (1980) study, which explored students' conceptions of light. The method of obtaining data was an 'interview-about-instances' technique (Osborne & Gilbert, 1980). The students were shown drawings on cards of instances of sources of light (for example, candle, television, heater, 'glow-in-the-dark' toy) both in daylight and night conditions, and reflectors of light (for example, moon, mirror, movie screen). Each student was shown the same sequence of cards and asked the same pair of questions for each card. The questions were:

1. Does the candle make light?
1a. (Why do you say that?)
2. What happens to the light the candle makes?
2a. (Does it stay around the candle or move out?)
2b. (About how far from the candle does the light from the candle go?)

Questions 1a, 2a and 2b were used, if needed, to elicit further information from the students. Other questions were modified and added where it was seen necessary to obtain a clearer understanding of the student's conceptions of luminosity and light propagation in daylight and night conditions.

In the second set of interviews the students' conceptions as they related to image formation in plane mirrors were explored using an approach used by Goldberg and McDermott (1986). The students were initially presented with a physical arrangement that involved a vertical rod placed in front of a plane mirror. The student and researcher were seated in front of the mirror in such a way that both could see an image of the rod; the student was seated to the right of the rod and the researcher was seated to the left. The student was provided with a diagram showing an overhead view of the arrangement of the mirror, rod, researcher and student. Some of the typical questions asked were, bearing in mind that, for some students, there was a modification of questions and follow-up questions in order to gain a clearer understanding of the student's conceptions:

1. Can you see an image of the rod in the mirror?
2. (Given an affirmative response from question 1). Where do you think the image actually is? Show me on the diagram.

3. If you were sitting where I am where do you think the image will be? Show me on the diagram.

The arrangement was now changed so that the mirror was covered and moved to the left of the student so that the mirror, rod and student were in the one line. With this arrangement, if the mirror was uncovered, the student would not be able to see the image of the rod but the researcher, who sat to the right of the student, could. The student was given an overhead diagram of the new arrangement and asked further questions, such as:

4. With this arrangement would you be able to see an image of the rod in the mirror now? (Given an affirmative response). Show me on the diagram.
5. Would I be able to see an image of the rod in the mirror? (Given an affirmative response). Show me on the diagram.

The third interview, conducted eight weeks after the teaching sequence, probed the conceptual understanding of all the key concepts of the study. Where the student had exposed an alternative conception either in the first two pre-instructional interviews or sometime during the teaching sequence supplementary questions were asked to probe for any change in conceptual understanding. Many of the questions were of the same type used in the tests administered during the teaching sequence. The students were presented with the questions in written form and many of the questions were accompanied with a diagram. The researcher verbally expressed each question, and if necessary, further explanation was provided. The students were expected to draw on the diagrams as well as provide verbal responses.

Findings

Each of the six case study students had several alternative conceptions as they related to seven key concepts of geometrical optics. There were alternative conceptions in each of the key concept areas that reflected pre-instructional ideas as well as alternative conceptions generated during the teaching sequence. Another finding that was found during and following the teaching sequence was related to the students' understanding of the nature of light. Each student on several occasions expressed the alternative conception that light actually consists of rays.

The following tables describe the alternative conceptions held by each student with respect to the key concept areas prior to the teaching sequence as well as those alternative conceptions present eight weeks following the teaching sequence. Each student has been given a pseudonym. One of the students, Christine, held a greater number of post-instructional alternative conceptions than the rest of the students. A possible reason may have been Christine's irregular attendances to class; she did not attend seven classes spread out over the teaching sequence.

Table II: Alan's Alternative Conceptions before and following the Teaching Sequence

Key Concept	Alternative Conceptions Pre-instruction	Alternative Conceptions Post-instruction
2.	Light from dim luminous objects does not travel very far from the object.	
3.	Each point on a luminous object emits light in one direction.	Each point on a luminous object emits light in one direction.
4.	The reflection rule does not hold true for curved mirrors.	The reflection rule is violated in explaining that the image of an object in front of a plane mirror is on the mirror.
5.	Light bends towards the normal when it passes from a transparent material into air.	Light bends towards the normal when it passes from a transparent material into air. Light can change direction when perpendicularly incident to an air/material interface.
6.	Objects have coloured components that change the colour of the incident light. The function of a filter is to change the colour of the transmitted light.	
7.	The image of an object in front of a plane mirror is directly in front of the object and on the mirror surface. An object that is not directly in front of a plane mirror has its image on the	The reflected light from a plane mirror carries the image to the observer's eye.

	surface of the mirror in a position midway between the object and the observer. The process of real image formation in a convex lens is similar to pinhole image formation where the lens replaces the pinhole. Each object point emits a single ray that carries all the structural information about the corresponding image point.	

While Alan showed evidence of holding pre-instructional alternative conceptions in several of the key concept areas he did have a scientific view of the vision process and specular and diffuse reflection of light. In terms of image formation in lenses Alan understood the process as one similar to that of pinhole image formation. He appeared to have constructed a view that each point on the object emits a single ray that carries all the structural information about the corresponding image point.

After the application of teaching strategies that directly addressed the alternative conceptions that were elicited, many of Alan's pre-instructional alternative conceptions were no longer apparent. The newly constructed scientific conceptions were still evident in the third interview that occurred two months after the Year 10 teaching stage. However, as Table II shows, there still remained alternative conceptions. Alan's inconsistency in predicting directional changes of light in explaining refraction effects may stem from an inability to consistently apply any of the teaching models taught in the teaching stage to predict the path of light through transparent materials. Alan's explanations of image formation in lenses were consistent with the key concept. However, he continued his thinking about light rays carrying the image information in his explanations of image formation in plane mirrors. Such a view is described by Galili, Bendall and Goldberg (1993) as a 'projected image conceptualisation'.

Table III: Beth's Alternative Conceptions before and following the Teaching Sequence

Key	Alternative Conceptions	Alternative Conceptions

Concept	Pre-instruction	Post-instruction
1.	Light only needs to illuminate an object before vision of that object is possible. Humans can see in the total absence of light after spending some time in dark conditions. Nocturnal animals can see in the total absence of light.	
2.	Light from a luminous object travels only as far as it can illuminate the area surrounding the luminous object. Light from a bright luminous source will travel further than a dim luminous source and light travels further at night than during the day.	
3.	Each point on a luminous object emits light in one direction.	Each point on a luminous object emits light in one direction.
5.	Light may change direction within a transparent material through reflecting on particles within the material.	
6.	The colour of an object is a physical property of that object. The function of a filter is to change the colour of the transmitted light.	The colour of the reflected light from an object is a mixture of the incident light and colour of the object itself.
7.	The image of an object in front of a plane mirror is the same distance behind the mirror as the object is in front of the mirror and its position is midway between the object and the observer. An object that is not directly in front	In a convex lens system the real image is formed at a lens then travels through space until captured by a screen where it may be observed.

	of a plane mirror has no image for any observer. In a convex lens system the real image is formed at the object then travels through space where it gets inverted by a lens and is finally captured by a screen where it may be observed.	

Beth showed evidence of holding pre-instructional alternative conceptions in several of the key concept areas. There was some evidence of alternative frameworks as coherent views where Beth linked her understanding of the vision process with the extent of light propagation from luminous sources. Her understanding of coloured objects was consistent with this linkage. However, there was also evidence of contextualised thinking such as vision in nil light conditions and the non-existence of a plane mirror image for an object placed to the side of the mirror. A holistic conceptualisation (Galili, Bendall & Goldberg, 1993), where the image is created at the object and travels through space, dominated Beth's pre-instructional thinking about the image formation process in a convex lens.

Throughout the teaching stage of the study there was significant growth in understanding with some retention of alternative conceptions. There remained evidence of a framework of understanding involving vision, extent of light propagation from luminous sources and coloured objects. Beth used her newly constructed scientific understanding of vision (key concept 1) to explain the extent of light propagation from luminous objects (key concept 2). In terms of her thinking about coloured objects Beth incorporated her scientific understanding of vision into her pre-instructional alternative conception. Beth's understanding of image formation in convex lenses become more analytical but still retained aspects of a holistic conceptualisation. Her thinking is characterised as a projected image conceptualisation (Galili, Bendall & Goldberg, 1993) where the image is carried by light rays acting like rails.

Table IV: Christine's Alternative Conceptions before and following the Teaching Sequence

Key Concept	Alternative Conceptions Pre-instruction	Alternative Conceptions Post-instruction
1.	Light only needs to illuminate an object for vision of that object to occur.	The image of an object in front of a plane mirror is on the mirror surface in a position midway between the object and the observer.
2.	The extent of light propagation from a luminous object depends on the brightness of the object. Light from a dim object stays around the object whereas light from a bright object travels some metres before fading away.	Light from luminous objects fades away with distance from the source.
3.	Each point on a luminous object emits light in one direction.	Each point on a luminous object emits light in one direction.
4.	Light reflects off non-mirrored surfaces specularly.	
5.		Light bends towards the normal when it passes from a transparent material into air. Light can change direction when perpendicularly incident to an air/material interface.
6.	The function of a filter is to change the colour of the transmitted light.	The colour of the reflected light from an object is a mixture of the colour of the incident light and the inherent colour of the object.
7.	The image of an object in front of a plane mirror is directly in front of the object and on the mirror surface. An object that is not directly in front of a plane mirror has no image for any observer. In a convex lens system the real image is formed at a lens then travels	The image of an object in front of a plane mirror is on the mirror surface in a position midway between the object and the observer. The reflected light from plane mirrors carries the image to the observer's eye. Ina convex lens systems the real

	through space until captured by a screen where it may be seen.	image is formed at the lens then travels through space until captured by a screen where it may be seen.

Before the teaching of the key concepts of geometrical optics Christine showed evidence of holding alternative conceptions in several of the key concept areas. Unlike Alan and Beth she had not developed firm views about what gives colour to an object or an explanation for refraction effects. In understanding real image formation in convex lenses there was a holistic conceptualisation of an image moving through space. This holistic conceptualisation was consistent with Christine's understanding that the image in a plane mirror is directly in front of the object on the mirror surface.

Many of the pre-instructional alternative conceptions were retained despite the adoption of teaching strategies to directly address them. This result was contrary to each of the other students and may be due, in part, to Christine's reported absences from her Year 10 studies. However, Christine did gain a scientific understanding of the vision process. This understanding was reflected in her alternative conceptions of the colour of objects, as Beth had done, and the placement of the image in a plane mirror. Christine had maintained her holistic conceptualisation of the real image formation process in a convex lens.

Table V: Danielle's Alternative Conceptions before and following the Teaching Sequence

Key Concept	Alternative Conceptions Pre-instruction	Alternative Conceptions Post-instruction
1.	Nocturnal animals and humans can see in the absence of light. Light only needs to illuminate an object for vision of that object to occur.	
2.	The extent of light propagation from a luminous object depends on the brightness of the object. Light from a dim object stays around the object whereas light from a bright object	

	travels some distance away. Light can bend around clouds.	
3.	Each point on a luminous object emits light in one direction.	
5.		An inability to apply key concept 5 to explain a novel refraction phenomenon.
6.	The colour of an object is an inherent property of the object. The function of a filter is to change the colour of the transmitted light.	The colour of an object is determined by what coloured light it absorbs.
7.	The image of an object in front of a plane mirror is directly in front of the object and on the mirror surface. An object that is not directly in front of a plane mirror has no image for any observer. In a convex lens system the real image is formed at the object then travels through space where it gets inverted by a lens and is finally captured by a screen where it may be seen.	The reflected light from a plane mirror carries the image to the observer's eye. The production of part of the real image formed by a convex lens is affected by obscuring part of the convex lens.

Danielle showed evidence of holding alternative conceptions in several of the key concept areas. Danielle's pre-instructional thinking was very similar in a number of ways to Beth. For example, the contextualised thinking of the ability to see in nil light conditions. Also, the coherence in thinking between vision of objects in light conditions with the extent of light propagation from luminous sources and colour of objects, thus suggesting a possible alternative framework. Danielle also showed evidence of a holistic conceptualisation for image formation in lenses. Like Christine, Danielle had limited views on refraction.

Throughout the teaching stage there was significant growth in understanding with some retention of alternative conceptions. There was now evidence of a framework of scientific understanding involving vision and extent of light propagation from luminous sources. Although this framework was consistent with Danielle's view of coloured objects there was confusion as to what coloured light gets reflected from the object. As with Beth and Christine, Danielle's thinking about image formation in a lens and plane mirror was one of a projected image conceptualisation (Galili, Bendall & Goldberg, 1993).

Table VI: Evan's Alternative Conceptions before and following the Teaching Sequence

Key Concept	Alternative Conceptions Pre-instruction	Alternative Conceptions Post-instruction
2.	Light from dim luminous objects only travels metres whereas light from brighter objects travel further. Light travels from luminous objects in waveforms.	
3.	Each point on a luminous object emits light in one direction.	Each point on a luminous object emits light in one direction.
4.	Non-mirrored surfaces reflect light specularly.	
5.		Light leaving a transparent material into air bends towards the normal.
6.	The function of a filter is to change the colour of the transmitted light.	
7.	The image of an object in front of a plane mirror is on the mirror surface in a position midway between the object and the observer. The image of an object placed to the side of a plane mirror does not exist for any observer. In a convex lens system the real image is formed at the object then travels through space where it gets inverted by a lens and is finally captured by a screen where it may be seen.	

Evan showed evidence of holding pre-instructional alternative conceptions in several of the key concept areas. However, he, like Alan, did have a scientific view of the vision process. Evan did not offer any views as to the phenomena of refraction or coloured objects. In terms of image formation in a convex lens he was analytical to some degree connecting the change in light direction with image formation. This thinking supports a projected image conceptualisation (Galili, Bendall & Goldberg, 1993). Like Beth, Evan showed contextualised thinking in terms the absence of an image when an object is placed to the side of a plane mirror.

During the teaching stage there was significant growth in understanding with some retention of alternative conceptions. The retention of the alternative conception that 'each point on a luminous source emits light in one direction' is consistent with each of the other students except Frank. The prevalence of the view that light deviation is towards the normal may suggest that Evan applied a general rule rather than considering if the light speeds up or slows down and applying a teaching model to determine the light direction.

Table VII: Frank's Alternative Conceptions before and following the Teaching Sequence

Key Concept	Alternative Conceptions Pre-instruction	Alternative Conceptions Post-instruction
1.	Light only needs to illuminate an object for vision of that object to occur.	Cats can see in nil light conditions.
2.	Light from luminous objects only travels as far as they are visible.	
3.	Each point on a luminous object emits light in one direction.	
4.	Non-mirrored surfaces reflect light specularly.	
5.	The change in direction when light passes from one transparent material into another is due to the reflection of light.	The change in direction when light passes from one transparent material into another is not always correctly predicted.
6.	The colour of the reflected light from	

	an object is obtained from the object. The function of a filter is to change the colour of the transmitted light.	
7.	The image of an object placed to the side of a plane mirror is in a position that is behind the mirror and can be seen by an observer on the same side of the mirror as the object. In a convex lens system the real image is formed at the object then travels through space where it gets inverted by a lens and is finally captured by a screen where it may be seen.	The reflected light from a plane mirror carries the image to the observer's eye. The real image formed by a convex lens is created by the perpendicularly incident light on the lens from the object. The image is created at the lens and keeps travelling until captured by a screen where it may be screen.

Before the teaching of the key concepts of geometrical optics Frank showed evidence of holding alternative conceptions in several of the key concepts. As with Beth and Danielle there was evidence of coherence in thinking about vision of objects in light conditions with the extent of light propagation from luminous sources and colour of objects, thus suggesting a possible alternative framework. Also common to Beth and Danielle, as well as Christine, was evidence of a holistic conceptualisation (Galili, Bendall & Goldberg, 1993) of real image formation in a convex lens.

Many of the pre-instructional alternative conceptions were no longer apparent following the Year 10 teaching stage suggesting significant growth in understanding. The alternative framework suggested in pre-instructional thinking was now a framework of scientific ideas. However, there still remained some alternative conceptions. The persistence of difficulties Frank had with changes in light direction in refraction effects was common to other students as was a projected image conceptualisation (Galili, Bendall & Goldberg, 1993) for image formation in convex lenses.

Discussion of the findings

This study found geometrical optics to be a rich area for the prevalence of alternative conceptions among a group of Year 10 students. The occurrence of alternative conceptions is not surprising given the wealth of research studies with similar findings. Among the pre-instructional alternative conceptions there was evidence of students holding contradictory views in different contexts. For example, the understanding on the one hand of the belief that vision of an object in daylight conditions is only possible if it is illuminated while on the other hand vision is possible in nil light conditions. In another example, students had the view that a plane mirror image is located on the mirror surface midway between the object and observer. The students believed this view only applied to objects located directly in front of the mirror even though the application of the view could also apply to objects located to the side of the mirror.

While there was evidence of students holding contradictory views there was also evidence of alternative frameworks. However, the prevalence of alternative frameworks should not be judged according to whether the framework acts as an alternative to an existing scientific theory, across a similar domain, but should be judged by the consistency with which it is used across a limited domain. There was consistency in the alternative conceptions described as 'the only condition for vision of an object is for it to be illuminated', 'the extent of light propagation is dependent on the degree to which it can illuminate the area surrounding the luminous object', and 'the colour of an object is a property of that object'.

The teaching sequence proved successful in changing the understanding of the students in several of the key concept areas to a scientific one. Much of this success may be attributed to the adoption of constructivist-informed teaching and learning approaches. Such approaches, which involve addressing the extant knowledge of the students, may have been a significant factor in changing the students' understanding of geometrical optics. The success in changing the students' understandings of optics contrasts with those findings within the research literature that found students' conceptions resilient to change in the face of instruction. There was very little evidence of students reverting to pre-instructional thinking once they showed evidence of holding a scientific understanding. However, there was evidence of students' inability to apply their newly constructed scientific understanding to novel situations. For example, students had difficulty in applying the key concept relating to refraction in explaining the presence of the displaced image when an object was viewed through the side of a triangular prism.

In contrast to the success in changing the students' understanding of optics through the application of constructivist-informed teaching and learning strategies there were difficulties incurred by the students in achieving a scientific understanding of some key concepts. These concepts related to the emission of light from luminous objects, refraction, colour of objects and image formation in plane mirrors and convex lenses.

A possible factor in the persistence of the alternative conception that light is emitted in only one direction from each point on the luminous source was the lack of the teaching of the treatment of a luminous object as an aggregate of point sources rather than an integrated whole. From this treatment of a luminous object students should realise that each point on the source is emitting light in the same manner as individual point sources do so; that is, isotropically.

The problems associated with refraction lay with the students' inability to correctly predict the path light follows in passing from one transparent medium into another. The students tended to use the same rule for the predicted light path, which corresponded to light entering a transparent material from air, for different situations. There was no evidence of the students applying any of the teaching models presented as part of the teaching and learning sequence to predict the light path. This situation may have been the result of an 'induced incorrect generalisation' (Mohapatra, 1988) in the students' thinking caused by too much emphasis in the teaching sequence on drawing ray diagrams of light entering a flat transparent material from air. Therefore, instead of the students thinking about light changing speed in passing from one transparent material into another and applying a teaching model to predict the light path they have consistently applied the one rule that 'light bends towards the normal'.

The resilience of the alternative conception that colour is an intrinsic property of an object may have been due to the ease with which the scientific understanding of vision can be assimilated with this conception and the complexities of using a colour theory to explain the perceived colour of objects in different coloured lighting conditions. The perception of colour by the human eye is quite complex and is often in conflict with everyday language, which supports the alternative conception, and past experiences in art classes mixing paints and crayons. The assimilation of the alternative conception relating to colour with the vision concept may be quite natural for students if they are unaware of the concept that light is a mixture of different coloured light. From this perspective, the importance of possessing a prior understanding that light from the sun and other luminous objects, such as light bulbs, is composed of different coloured light would make it a key concept necessary to be understood before addressing the colour concept.

The lack of success in changing students' views about the emission of light presented a barrier to the scientific understanding of image formation process in mirrors and lenses. Another barrier to the image formation process in this research study was the students' understanding of a ray as a physical entity of light. This led students to progress from a holistic conceptualisation of an image travelling freely through space to a projected image conceptualisation of the image carried by rays acting like rails. Galili (1996) and, Galili, Bendall and Goldberg (1993) believe the projected image conceptualisation to be a well-defined intermediate state of knowledge of post-instructional students. The findings of this study support such a view given that each student passed through this conceptualisation before reaching a scientific understanding. Further research is needed to determine to what extent student thinking about the emission of light from luminous objects and ideas about the ray present a barrier to a scientific understanding of image formation and the construction of a projected image conceptualisation.

Implications for teaching geometrical optics

The existence of an alternative framework, such as that described above, has implications for the teaching and learning of the scientific concepts related to the framework. The coherence with which a student holds several alternative conceptions may make it difficult to change any one of the alternative conceptions. However, a change in thinking about any one of the alternative conceptions will bring into conceptual conflict the understanding of the other related conceptions in the mind of the student. This study found that the addressing of the students' alternative conception related to vision was profitable in terms of changing the students' views related to other areas in respect of their alternative framework. There was evidence of the students using their newly constructed conception of vision in arguing for the scientific concept of light propagation. For example, the students argued that light from a dim light source travels away from the source as it can be seen from some distance away. The students' newly constructed understanding of vision also brought into conflict their views about the colour of objects. However, instead of accommodating the scientific concept the students assimilated their understanding of vision into their existing understanding of coloured objects. This produced a hybrid alternative conception where the reflected light that enters the observer's eyes is coloured through interacting with the observed object.

In terms of the teaching of geometrical optics at Middle School an initial approach would be to elicit and address any alternative conceptions that relate to vision. A scientific understanding of the vision process allows for the use of the eye as a light detector in discussions and activities involving other concepts. The idea that to see an object implies light is entering the eye gives plausibility to concepts involving rectilinear propagation, diffuse reflection, colour and image formation in mirrors and lenses. For example, a plausible argument can be made whereby the ability to see a point on an object from many directions implies that light is reflecting in many directions from the point. As light enters the eye from an observed object it seems plausible that information about the colour of the object is related to the colour of the reflected light. Similarly, the observed image in a plane mirror has a relationship to the reflected light that enters the eye. The exploration of the wider applications of the vision concept enhances the construction of a framework of scientific ideas and at the same time addresses contextualized thinking. The exploration of the wider applications of other concepts, such as the reflection rule, also proves successful in consolidating scientific ideas.

The difficulties in changing the students' views related to the emission of light from luminous objects, refraction, colour of objects and image formation in plane mirrors and convex lenses has implications for the teaching of these areas, particularly to addressing the possible factors that give rise to persistent difficulties.

An implication for the teaching of the key concept of isotropic emission of light from each point on a luminous object is for this concept to be reinterpreted to a more fundamental concept that luminous objects are composites of point sources of light. The teaching and learning strategies developed by the teacher in the area of emission of light from luminous objects should then focus on this key concept. In addition, students' consolidation of this concept needs to precede the introduction of ideas about image formation in lenses and mirrors.

An implication for the teaching and learning of refraction may be that students require a range of situations to predict the light path through transparent materials. These situations should include: (a) the passage of light as it enters and leaves transparent materials, (b) different angles of incidence, (c) curved interfaces, and (d) different combinations of transparent materials. Given the multitude of different situations, students may find that the application of a teaching model, or their own model, provides a more useful mechanism for predicting the light path than remembering a number of rules, each one applicable to a specific situation. The model emphasises that a change in speed occurs, which defines the phenomenon of refraction, rather than a rule that emphasises a change in direction.

Teaching and learning strategies that consolidate the understanding the concept light from luminous objects such as the sun is composed of different coloured light would make it a key concept necessary to be understood before addressing the classroom discussions about the perceived colour of objects. From a teaching and learning perspective care needs to be taken in developing scientific ideas about colour. The teacher needs to look continually for evidence of students harbouring the alternative conception that colour is an intrinsic property of an object. Such monitoring is particularly important where students are required to use a simple colour theory to predict the apparent colour of objects in different lighting conditions.

From a curriculum perspective the scientific model of a ray is important to the explanations of a whole range of optical phenomena within the topic of geometrical optics. However, this study found the students' conceptual model of a ray as a physical entity of light presented a barrier to a conceptual understanding of some key concepts. Given the central place ray diagrams play in the explanation of a whole range of optical phenomena, then a focus on the ray scientific model within the classroom needs to be given in conjunction with ideas about the nature of light. To not attend to ideas about the nature of light at all, a common occurrence in many secondary school geometrical optics courses, leaves the student with little option but to construct a view of light as consisting of rays. That is of course if the student has not already constructed this view before instruction, given the everyday use of the term 'ray'. For many students a course in geometrical optics may reinforce pre-instructional conceptual models about the ray as a constituent of light. Further study in optics following a geometrical optics course leads to ideas about the nature of light in courses described as physical optics and quantum ideas. Students entering such courses may then have well entrenched non-scientific conceptual models of the nature of light. Curriculum planners and teachers need to be well aware of the possibility of this situation arising.

The change in thinking from a ray as a physical entity to a ray as a graphical representation represents a conceptual change across ontological categories and may be difficult to achieve (Chi, 1992). In describing the historical change in thinking about the ray, Galili and Lavrik (1998) suggest, "Light rays complete a dramatic metamorphosis from the concept of central importance, the essence of light, to an auxiliary tool of semantic nature, a subordinate notion" (p. 603). Reinterpreting the ray concept for the students leaves them with a void in terms of perceptions about the nature of light. One may then argue that a teaching sequence that focuses on a scientific understanding of a ray needs to go hand in hand with discussions on the development of ideas about the nature of light, namely the scientific models of the nature of light. For example, light spreading from a point source can be represented by water waves spreading from a single disturbance. The waves have an associated ray that gives the direction of propagation of the waves. Light reflection can be represented by a ball bouncing off a wall. The ray gives the direction of propagation of the ball.

Classroom discussion about the scientific understanding of the term 'ray' needs to be contrasted with the everyday usage of the term and inappropriate usage in some textbooks. Students need to appreciate that there are times when scientific meanings to terms differ from their everyday usage and that it is quite appropriate to attach different meanings of such terms depending on the context of the terms' use. While Galili and Lavrik (1998) argue for the replacement of the classroom teaching of a ray with a flux idea to offset misinterpretations of the ray the use of the ray scientific model allows the use of ray diagrams to explain a whole range of optical phenomenon. The success of the ray model to explain and make predictions in geometrical optics is very compelling as distinct from other areas of physics. For example, Newton's Laws do not readily explain everyday observations relating to forces and motion unless frictional effects are taken into account.

If ideas about the nature of light through the scientific models of light are incorporated into the Middle School optics curriculum then as each new phenomenon of light is explored an appropriate scientific model is used to explain the observations made. A curriculum emphasis during the teaching period of geometrical optics on the nature of light and its accompanying scientific models may make it a matter of course for students to think about refraction in terms of the application of a model.

From a teaching and learning perspective students' alternative conceptions associated with the emission of light from luminous objects and understandings of the ray need to be addressed before the teaching of image formation in mirrors and lenses. In addition, rays diagrams to explain image formation should be considered incomplete if they do not include multiple rays from points on the object. This reinforces the concept that a flux of light emanating from each object point contributes to the production of the image. The inclusion of an eye in the diagram is also important, particularly in cases where a virtual image is formed.

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